DESCRIPTION

COMBUSTION APPARATUS

Technical Field

The present invention relates to a combustion apparatus, and more particularly to a combustion apparatus for supplying combustion air and fuel to a combustion chamber to mix and combust the combustion air and the fuel.

Background Art

Regulation regarding air pollutants discharged from a combustion apparatus, particularly nitrogen oxide (NOx), becomes stricter and stricter. Thus, there has been demanded technology to reduce discharge of NOx.

Nitrogen oxide (NOx) is generally classified according to its generation mechanism into three types: thermal NOx, prompt NOx, and fuel NOx. Thermal NOx is generated when nitrogen in air reacts with oxygen at a high temperature, and greatly depends on temperature. Prompt NOx is generated particularly in a flame of fuel-rich condition. Fuel NOx is generated while nitrogenous compounds contained in fuel are converted.

Recently, clean fuel including no nitrogenous compounds has been used in many cases. In such cases, fuel NOx is hardly generated. When a design of fuel-rich combustion is modified into a design of lean combustion in order to reduce prompt NOx, the generation of prompt NOx can be suppressed. As compared to the aforementioned reduction of fuel NOx and prompt NOx, reduction of thermal NOx is most difficult and is becoming a key of NOx reduction technology in recent years.

Here, it is important to lower a combustion temperature in order to reduce thermal NOx. Technology to lower a combustion temperature includes premixed combustion, particularly lean premixed combustion, pre-evaporation, rich and lean combustion, two-stage combustion, burnt gas recirculation, and the like.

In a case of gaseous fuel, a uniform distribution of fuel concentration can be achieved by premixed combustion in which fuel is sufficiently mixed with air, then ignited, and combusted, and a combustion temperature can be lowered particularly by premixed combustion in fuel-lean condition. However, premixed combustion has problems that a stable combustion range is so narrow that backfire or blow-off is likely to occur. Further, there is a defect that liquid fuel cannot be premixed unless the fuel has previously been evaporated (pre-evaporated).

In a case of liquid fuel, fuel to be injected is atomized when the fuel passes through nozzles having a small passage cross-section. Usually, droplets of the fuel remain at the time of ignition. Since combustion occurs while the droplets are being evaporated, a location with a theoretical air ratio is inevitably produced, and temperature locally increases. Thus, there is a limit to reduction of thermal NOx.

Pre-evaporation has been known as technology to solve the above problems. In pre-evaporation, a pre-evaporation portion is provided inside or outside of a combustor, and fuel is sprayed into the pre-evaporation portion, evaporated by heating from an external source, and then combusted. According to the pre-evaporation, thermal NOx reduction equivalent to that in the case of gaseous fuel can be expected. However, the size of the combustion apparatus problematically becomes large by the pre-evaporation portion.

Further, fuel or air is divided into several stages and supplied into a combustion apparatus so that air ratios are controlled at each region in a combustion chamber. In this case, a portion having a fuel concentration higher than a theoretical air ratio and a portion having a fuel concentration lower than the theoretical air ratio are intentionally formed so as to avoid a mixed state region with the theoretical air ratio, thereby reducing thermal NOx.

However, such technology has been employed in many large-sized combustion furnaces but cannot be applied to small-sized combustion apparatuses because a supply system of fuel or air becomes complicated. Further, it is difficult to find optimal supply

locations of fuel or air and optimal division ratios, or to control these locations and division ratios according to loads.

Burnt gas recirculation is technology to achieve slow and uniform combustion by mixing a combustion gas having a high temperature and a low oxygen concentration with combustion air. Thus, a combustion temperature is lowered while an inert gas is increased so as to increase a heat capacity. An average flame temperature is lowered. Hence, thermal NOx is reduced. The burnt gas recirculation is applied mainly to a combustion apparatus in a boiler and an industrial furnace, and an engine.

Methods to produce burnt gas recirculation include use of a flame holder, external recirculation, and internal recirculation. Combustion methods called flue gas recirculation (FGR) or exhaust gas recirculation (EGR) have been known but are basically the same technology as the burnt gas recirculation.

For example, Japanese laid-open patent publication No. 2002-364812 discloses an example using burnt gas recirculation for gaseous fuel. Japanese patent No. 3139978 discloses an example using burnt gas recirculation for premixed combustion of gaseous fuel. In either case, a combustion gas is recirculated in a recirculation region formed centrally downstream of a flame holding plate and in a space between a combustion apparatus projecting in a combustion chamber and a combustion chamber wall.

However, a burnt gas recirculation flow centrally downstream of the flame holding plate does not reach a portion in which fuel is mixed with air before ignition. The burnt gas recirculation flow serves merely to stabilize ignition. Actually, a burnt gas recirculation flow from the space between the combustion apparatus and the combustion chamber wall is circulated only near the combustion apparatus. Accordingly, a combustion gas that has been sufficiently combusted so as to have a high temperature and a low oxygen concentration is not recirculated, and the amount of circulation is small. Thus, reduction effect of thermal NOx becomes small.

Further, in these combustion apparatuses, the size of the combustion chamber must be sufficiently larger than the diameter of the combustion apparatus in order to draw

a burnt gas recirculation flow from the outside of the combustion apparatus in a direction of a central axis. Accordingly, this technology is not suited for purposes where the size of a combustion chamber of a combustion apparatus of a gas turbine or the like should be made as small as possible. Further, it is difficult to apply this technology to liquid fuel.

For example, Japanese laid-open patent publication No. 9-133310 discloses technology regarding gaseous fuel to recirculate a combustion gas from a rear central portion of a flame holding plate by the flame holding plate, produce a lifted and divided flame, and recirculate a combustion gas from a lateral portion of the flame. According to this technology, the amount of burnt gas recirculation can be increased. However, a structure of a burner becomes complicated due to the divided flame. A cross-section of the burner includes a portion having no flame. Accordingly, the size of the burner problematically becomes large (a combustion load per volume is low). Further, it is difficult to apply this technology to liquid fuel.

For example, in a combustion apparatus using premixed combustion of gaseous fuel for a boiler disclosed in Japanese laid-open patent publication 11-153306, a plurality of premixed gas injection holes are provided in a combustion chamber wall, and a premixed gas is injected as a combustion gas toward an adjacent premixed gas injection hole. However, since fuel and air have previously been mixed, fresh air is involved in combustion at the time of ignition and mixed with a combustion gas only after starting combustion. Accordingly, there is a problem that effect to make combustion slow is small. Further, this technology relates to premixed combustion for gaseous fuel. A premixed gas reaches a next injection hole in a short period of time. It is difficult to apply this technology to liquid fuel.

For example, in a burner for a boiler disclosed in Japanese patent No. 3171147, a low-pressure portion is formed by kinetic energy of combustion air flowing around a fuel nozzle, mainly with respect to liquid fuel. A combustion gas in a furnace is drawn and mixed with the combustion air. However, since the combustion gas is mixed outside of the combustion air, the combustion gas is hardly mixed inside of the combustion air.

Fuel is first mixed with the combustion air and then gradually mixed with the combustion gas. Accordingly, a combustion phenomenon depends on combustion air having the same oxygen concentration as usual, and hence slow ignition and combustion under a low oxygen concentration cannot be achieved sufficiently. Further, a structure for drawing a combustion gas is complicated. Furthermore, since a divided flame is employed, the burner has a complicated structure. A cross-section of the burner includes a portion having no flame. Accordingly, the size of the burner problematically becomes large (a combustion load per volume is low).

For example, Japanese patent publication No. 2000-179837 discloses technology in which a swirling flow is induced in a cylindrical combustion apparatus so that static pressure is lowered at a central portion of the swirling flow to thereby draw another gas from a normal direction of a swirling surface into a swirling center. This technology is applied to burnt gas recirculation at a secondary combustion zone in a cylindrical combustion apparatus. Not only supply of primary air and secondary air for combustion, but also supply of fuel serve to induce a swirling flow. However, effect of recirculation of the combustion gas introduced by the swirling flow is limited to combustion control at a secondary combustion zone. A region of a high fuel concentration near a flame is not a targeted region of the burnt gas recirculation. Accordingly, NOx reduction effect is limited only to temperature control at an end portion of flame.

Next, a specific arrangement of a conventional combustion apparatus and problems of the conventional combustion apparatus will be described in greater detail with reference to FIGS. 1 through 4.

FIG. 1 shows an example of a conventional general combustion apparatus. The combustion apparatus shown in FIG. 1 is a cylindrical combustion apparatus and has a cylindrical container 2001, an inflow casing 2002, a partition cylinder 2004, a fuel nozzle 2005, and a flame holding plate 2006 disposed downstream of the fuel nozzle 2005 and coaxially with the fuel nozzle 2005. Inflow passages are formed by the cylindrical container 2001, the inflow casing 2002, and the partition cylinder 2004.

Combustion air 2010 flows into the inflow casing 2002, flows through a space 2012 between the partition cylinder 2004 and the fuel nozzle 2005, and then flows near the flame holding plate 2006 into the cylindrical container 2001 by a blower or a compressor (not shown).

On the other hand, fuel 2014 is injected through the fuel nozzle 2005 into the cylindrical container 2001 by a fuel pump, a blower, or a compressor (not shown). The fuel 2014 is mixed with the combustion air 2010 and combusted to produce a combustion gas 2016. The produced combustion gas 2016 flows out of an open end 2007 of the cylindrical container 2001.

Here, the flame holding plate 2006 allows stable ignition. In the example shown in FIG. 1, the flame holding plate 2006 is in the form of a cone having a larger diameter near the open end 2007. The flame holding plate 2006 blocks a flow of air flowing through the space 2012 between the partition cylinder 2004 and the fuel nozzle 2005, reduces a velocity of flow of the combustion air 2010 at a tip of the fuel nozzle 2005, and forms a flow region 2018, in which air flows backward from a downstream region, at a downstream side of the flame holding plate 2006. The back flow 2018 returns a combustion gas 2016 having a high temperature to an ignition region right downstream of the tip of the fuel nozzle 2005.

However, the back flow of the combustion gas is present only at an inner side 2020 of a fuel track 2014 but does not reach a portion at which the fuel 2014 is mixed with the air 2010. Accordingly, a function of the back flow of the combustion gas is merely to stabilize ignition.

An example of an annular combustion apparatus to which the combustion apparatus shown in FIG. 1 is directly applied will be described with reference to FIGS. 2A and 2B. As described above, in the case of the cylindrical combustion apparatus shown in FIG. 1, the flame holding plate 2006 is in the form of a cone. However, in the case of the annular combustion apparatus shown in FIGS. 2A and 2B, an annular flame holding plate 2006a is employed as shown in FIG. 2B.

As shown in FIG. 2B, a plurality of cylindrical fuel nozzles 2005 may be attached to the flame holding plate 2006a. An annular fuel nozzle (not shown) may be employed. Effects of the fuel nozzles 2005 are the same as those in the case of the cylindrical combustion apparatus shown in FIG. 1.

An arrangement, effects, and problems of a conventional combustion apparatus which utilizes burnt gas recirculation will be described with reference to FIG. 3. A combustion apparatus shown in FIG. 3 is a cylindrical combustion apparatus, which is applied to boilers or industrial furnaces. The combustion apparatus has a first swirler 2003 through which combustion air 2010 passes, a second swirler 2030 disposed outside of an annular container 2001, and an outer cylinder 2031 in addition to the arrangement of the conventional combustion apparatus shown in FIG. 1

The swirler 2003 swirls a flow of the combustion air 2010 to form a negative pressure region at the center of the swirling flow so as to form a flow region 2019 in which the air flows back from a downstream side of the flow region 2019. The back flow 2019 returns a combustion gas 2016 having a high temperature to an ignition region right downstream of the tip of the fuel nozzle 2005. Thus, the swirler 2003 stabilizes ignition as with the flame holding plate 2006.

When the second swirler 2030 is located away from a combustion chamber wall 2032, the combustion gas 2016 in a combustion chamber is drawn through the second swirler 2030 by induction effect of the flowing combustion air 2010, mixed with the combustion air 2010, and combusted.

This is a typical example of conventional technology which utilizes burnt gas recirculation. Since the combustion gas 2016 is introduced from an outside of the swirling flow of the combustion air 2010, the combustion gas 2016 is hardly mixed inside of the combustion air 2010. The fuel 2014 is first mixed with the combustion air 2010 and gradually mixed with the combustion gas 2016. Accordingly, combustion phenomenon depends on the combustion air 2010 having the same oxygen concentration as usual, and hence ignition and combustion under a low oxygen concentration cannot be

achieved.

Further, in the combustion apparatus shown in FIG. 3, since a burnt gas recirculation flow is drawn from an outside of the outer cylinder 2031, the size of the combustion chamber must be sufficiently larger than the diameter of the outer cylinder 2031. Accordingly, this combustion apparatus is not suited for purposes of a combustion apparatus of a gas turbine or the like where the size of the combustion chamber should be made as small as possible. Furthermore, the combustion apparatus shown in FIG. 3 is not suited for application to an annular combustion apparatus.

An arrangement, effects, and problems of a conventional annular gas turbine combustion apparatus will be described with reference to FIG. 4. A conventional combustion apparatus of a gas turbine has a extremely low total air ratio because a targeted temperature is considerably lower than a flame temperature in combustion with a theoretical amount of air, i.e., just the amount of air containing oxygen required for combustion of fuel. When general hydrocarbon fuel is used, it is difficult to combust the fuel by a single stage with such total air ratio.

For this reason, supply of the combustion air is divided into several stages. First, fuel is mixed with only a portion of the combustion air (primary air 2040) and combusted. Then, the rest of the combustion air is added. Thus, complete combustion is achieved under a desired outlet temperature.

A region from a location at which combustion air of the first stage is mixed with fuel in the container 2001a to air inflow portions of the second stage is referred to as a primary combustion zone 2042. With regard to combustion in a gas turbine, many technical ideas to add air downstream of the primary combustion zone 2042 have been known to prevent a lowered combustion efficiency, discharge of unburnt components, and increase of NOx.

In FIG. 4, the reference numeral 2044 represents air holes formed in the container 2001a, and the reference numeral 2046 represents secondary and dilution air flowing from the air holes 2044 into the container 2001a.

As described above, combustion under a low oxygen concentration by burnt gas recirculation has been known as an effective method for reducing thermal NOx. However, there are no conventional combustion apparatuses, directed to combustion under a low oxygen concentration by burnt gas recirculation, which have a sufficient amount of burnt gas recirculation or NOx reduction effects and there are no conventional combustion apparatuses which can achieve pre-evaporation combustion even with liquid fuel and premixed combustion as with gaseous fuel.

Disclosure of Invention

The present invention has been proposed in view of the above drawbacks of the conventional technology. It is, therefore, an object of the present invention to provide a combustion apparatus which has a relatively simple structure, can maximize effects of burnt gas recirculation, can achieve pre-evaporation in a case of liquid fuel, premixed combustion in a case of gaseous fuel/liquid fuel, and slow combustion under a low oxygen concentration, and can suppress generation of NOx.

Further, another object of the present invention is to provide a combustion apparatus suitable for inexpensively achieving use of ceramics to improve high-temperature resistance, particularly a combustion apparatus which can simplify a structure and reduce cost when applied to a gas turbine combustion apparatus.

According to a first aspect of the present invention, there is provided a combustion apparatus which can positively control and generate burnt gas recirculation with a simple structure. The combustion apparatus has an annular container having an inner cylindrical portion forming an inner circumferential side surface, an outer cylindrical portion forming an outer circumferential side surface, an open end, and a close end; an air supply portion for supplying combustion air into the annular container so as to have a velocity component in a direction of a central axis of the annular container from the open end to the close end of the annular container; and a fuel supply portion for supplying fuel into the annular container so as to have a velocity component in the

direction of the central axis of the annular container from the close end to the open end of the annular container. A flow of the combustion air supplied into the annular container first crosses a track of the fuel at a region away from the fuel supply portion and then crosses the track of the fuel again at a region near the fuel supply portion.

According to the present invention, the combustion apparatus has a combustion chamber having an annular cross-section and is configured so that a flow of the supplied air first crosses a track of the supplied fuel at a region away from the fuel supply means and then crosses a track of the supplied fuel again at a region near the fuel supply means. Accordingly, it is possible to positively generate burnt gas recirculation with a simple structure. Thus, when the present invention is applied to a general combustion apparatus, it is possible to enhance the stability and maximize effects of burnt gas recirculation.

Since effects of burnt gas recirculation can be maximized with high stability, it is possible to perform combustion with a combustion gas having a high temperature and a low oxygen concentration. Accordingly, it is possible to achieve pre-evaporation combustion having stable evaporation characteristics in a case of liquid fuel, in which it has been difficult to reduce NOx with the conventional technology, premixed combustion in either case of gaseous fuel or liquid fuel, slow combustion, uniform combustion with a low maximum flame temperature, and combustion with a low average flame temperature due to the heat capacity of an inert gas in the combustion gas. Therefore, it is possible to suppress thermal NOx, which has been difficult to suppress with the conventional technology.

Here, in the combustion chamber having an annular cross-section, the track of the air and the track of the fuel are not the same, and the track of the air and the track of the fuel intersect each other two times. The track of the air flow first crosses a track of the fuel flow near a tip of the fuel track and then crosses the track of the fuel flow again at a region from a root of the track of the fuel flow to the vicinity of the tip. In order to meet the above requirements, for example, the air flow and the fuel flow are opposed in a state such that the air flows in an opposite direction of the outlet direction while the fuel

flows in the outlet direction, and the fuel spreads outwardly in a direction perpendicular to the central axis of the combustion chamber (outwardly in a radial direction in a case of a cylindrical container) as the fuel is farther from an injection side.

According to a second aspect of the present invention, there is provided a combustion apparatus which can positively control and generate burnt gas recirculation with a simple structure. The combustion apparatus has an annular container having an inner cylindrical portion forming an inner circumferential side surface, an outer cylindrical portion forming an outer circumferential side surface, an open end, and a close end; an inflow passage for supplying combustion air into the annular container, the inflow passage being formed at a location away from the close end in a direction of a central axis of the annular container so as to extend through the outer circumferential side surface of the annular container; and a fuel nozzle provided inside of the close end of the annular container for supplying fuel into the annular container. The inflow passage is configured so as to form a flow of the air with a velocity component in the direction of the central axis of the annular container from the open end to the close end and a velocity component to swirl in a circumferential direction of the annular container. The fuel nozzle is configured so as to inject the fuel toward the inflow passage with a velocity component in the direction of the central axis of the annular container from the close end to the open end and a velocity component directed radially outward.

According to a third aspect of the present invention, there is provided a combustion apparatus which can positively control and generate burnt gas recirculation with a simple structure. The combustion apparatus has an annular container having an inner cylindrical portion forming an inner circumferential side surface, an outer cylindrical portion forming an outer circumferential side surface, an open end, and a close end; an inflow passage for supplying combustion air into the annular container; and a fuel nozzle for supplying fuel into the annular container. The outer cylindrical portion has a portion having a reduced diameter at a location away from the close end along a central axis of the annular container by a predetermined distance. The inflow passage is formed

at the portion having a reduced diameter in the outer cylindrical portion and is configured so as to form a flow of the air with a velocity component in the direction of the central axis of the annular container from the open end to the close end and a velocity component to swirl in a circumferential direction of the annular container. The fuel nozzle is configured so as to inject the fuel toward the inflow passage with a velocity component in the direction of the central axis of the annular container from the close end to the open end and a velocity component directed radially outward.

According to a fourth aspect of the present invention, there is provided a combustion apparatus which can positively control and generate burnt gas recirculation with a simple structure. The combustion apparatus has an annular container having an inner cylindrical portion forming an inner circumferential side surface, an outer cylindrical portion forming an outer circumferential side surface, an open end, and a close end; a cylindrical member disposed substantially coaxially with a central axis of the annular container and positioned on the open end side of said outer cylindrical portion, the cylindrical member having a diameter smaller than that of the outer cylindrical portion; an annular connecting member connecting an end of the outer cylindrical portion and an outer circumferential surface of the cylindrical member to each other; an inflow passage formed in the connecting member for supplying combustion air into the annular container; and a fuel nozzle provided inside of the close end of the annular container for supplying fuel into the annular container. The inflow passage is configured so as to form a flow of the air with a velocity component in the direction of the central axis of the annular container from the open end to the close end and a velocity component to swirl in a circumferential direction of the annular container. The fuel nozzle is configured so as to inject the fuel toward the inflow passage with a velocity component in the direction of the central axis of the annular container from the close end to the open end and a velocity component directed radially outward.

According to a fifth aspect of the present invention, there is provided a combustion apparatus which can positively control and generate burnt gas recirculation

with a simple structure. The combustion apparatus has an annular container having an inner cylindrical portion forming an inner circumferential side surface, an outer cylindrical portion forming an outer circumferential side surface, an open end, and a close end; an annular member disposed substantially coaxially with a central axis of the annular container and positioned on the open end side, the annular member having an inner cylindrical portion forming an inner circumferential side surface and an outer cylindrical portion forming an outer circumferential side surface and having a diameter smaller than that of the outer cylindrical portion of the annular container; a first connecting member connecting an end surface, on the open end side, of the outer cylindrical portion of the annular container and an outer circumferential surface of the outer cylindrical portion of the annular member to each other; a second connecting member connecting an end surface, on the open end side, of the inner cylindrical portion of the annular container and an end surface of the inner cylindrical portion of the annular member to each other; an inflow passage formed in the first connecting member for supplying combustion air into the annular container; and a fuel nozzle provided inside of the close end of the annular container for supplying fuel into the annular container. The inflow passage is configured so as to form a flow of the air with a velocity component in the direction of the central axis of the annular container from the open end to the close end and a velocity component to swirl in a circumferential direction of the annular container. The fuel nozzle is configured so as to inject the fuel toward the inflow passage with a velocity component in the direction of the central axis of the annular container from the close end to the open end and a velocity component directed radially outward.

An additional inflow passage may be provided in the inner cylindrical portion of the annular container for supplying air into the annular container. An additional inflow passage (auxiliary air inflow port) may be provided on the close end at a location near the inner cylindrical portion of the annular container and may be positioned radially inward from the fuel nozzle so that air flows in the direction of the central axis of the annular container. An additional inflow passage may be provided in the outer cylindrical portion

of the annular container for supplying air inwardly in a radial direction of the annular container. The combustion apparatus may further have a flow adjusting structure disposed on the close end within the annular container and/or on the outer cylindrical portion of the annular container near the close end for suppressing a swirling flow of the air near the close end.

The combustion apparatus may further have a flow adjusting structure (guide vane) disposed on the close end within the annular container and/or on the outer cylindrical portion of the annular container near the close end for converting a flow of air having a velocity component in a direction of the central axis of the annular container from the open end to the close end and swirling in a circumferential direction of the annular container into a flow directed inwardly in a radial direction of the annular container near the close end.

An additional fuel nozzle may be provided at a location closer to the close end than the inflow passage with respect to the direction of the central axis of the outer cylindrical portion of the annular container.

According to the present invention, the fuel flow has a velocity component in the direction of the central axis of the combustion chamber and a velocity component directed from the central axis of the combustion chamber toward a wall surface of the combustion chamber, i.e., a velocity component directed radially outward. The air flow has a velocity component in an opposite direction of the central axis of the combustion chamber and a velocity component to swirl in a circumferential direction. The flow of the fuel has a velocity component in the direction of the outlet of the combustion apparatus, and the flow of the combustion air has a velocity component in an opposite direction to the direction of the outlet. Accordingly, the aforementioned flows can be achieved.

According to the present invention, a portion of the flow of the air supplied from the air supply means (inflow passage) into the combustion chamber flows as a combustion gas having a low temperature or an air flow not being a combustion gas along an inner wall surface of the combustion chamber. As a result, the inner wall of the

combustion apparatus is protected from heat in the combustion apparatus by the combustion gas having a low temperature or the air flow not being a combustion gas. Consequently, it is possible to provide a combustion apparatus having a high durability to combustion heat.

As described above, according to the present invention, it is possible to provide a simple structure which can positively control and generate burnt gas recirculation. Accordingly, it is possible to provide a combustion apparatus which can readily use a heat resistant material such as ceramics, can facilitate disassembly and part replacement, and has easiness of maintenance.

When an auxiliary fuel nozzle is provided, it is possible to provide a combustion apparatus which can suppress generation of thermal NOx in combustion with multi fuel of gaseous fuel/liquid fuel and combustion with fuel having a low heating value or a waste liquid.

When the present invention having the above arrangement is applied to a primary combustion zone of a gas turbine combustion apparatus, it is possible to positively generate burnt gas recirculation with a simple structure. Thus, the stability can be enhanced in the primary combustion zone of the gas turbine combustion apparatus, and effects of burnt gas recirculation can be maximized.

In the gas turbine combustion apparatus to which the present invention is applied, the primary combustion zone can be designed to be leaner because of high stability. Accordingly, it is possible to lower an average combustion temperature so as to further suppress generation of thermal NOx.

Further, in the gas turbine combustion apparatus to which the combustion apparatus of the present invention is applied, it is possible to enhance the stability and maximize effects of burnt gas recirculation. Accordingly, it is possible to suppress generation of thermal NOx in a case of liquid fuel, in which it has been difficult to reduce NOx with the conventional technology.

As described above, in the combustion apparatus of the present invention, since

an inner wall of the combustion apparatus is suitably cooled by an air flow having a low temperature, it is possible to provide a gas turbine combustion apparatus having a high durability.

Further, in the combustion apparatus of the present invention, because of a simple structure, it is possible to provide a gas turbine combustion apparatus which can readily use a heat resistant material such as ceramics, facilitate disassembly and replacement, and has easiness of maintenance.

Additionally, in a gas turbine to which a combustion apparatus of the present invention is applied, since a liner can be exposed while no air flows outside of the primary combustion zone, a fuel nozzle and an ignition device can be disposed with a simple structure, so that cost can be reduced.

Additionally, since thermal expansion of the liner can be reduced with respect to the casing, the structure can be simplified. Accordingly, it is possible to further reduce cost.

When a gas turbine is formed by a combustion apparatus having an auxiliary fuel nozzle, it is possible to suppress generation of thermal NOx in multi fuel combustion of gaseous fuel/liquid fuel and combustion with fuel having a low heating value or a waste liquid.

Brief Description of Drawings

FIG. 1 is a cross-sectional view showing a conventional cylindrical combustion apparatus;

FIG. 2A is a cross-sectional view showing a conventional annular combustion apparatus;

FIG. 2B is a front view of FIG. 2A;

FIG. 3 is a cross-sectional view showing another example of a conventional cylindrical combustion apparatus;

FIG. 4 is a cross-sectional view showing a conventional annular combustion

apparatus for a gas turbine;

FIG. 5 is a perspective view showing a combustion apparatus according to a first embodiment of the present invention;

FIG. 6 is a cross-sectional view of FIG. 5;

FIG. 7 is a perspective view showing a combustion apparatus according to a second embodiment of the present invention;

FIG. 8 is a cross-sectional view of FIG. 7;

FIG. 9 is a perspective view showing a combustion apparatus according to a third embodiment of the present invention;

FIG. 10 is a cross-sectional view of FIG. 9;

FIG. 11 is a perspective view showing a combustion apparatus according to a fourth embodiment of the present invention;

FIG. 12 is a cross-sectional view of FIG. 11;

FIG. 13 is a perspective view showing an example of a swirler in the embodiments of the present invention;

FIG. 14 is a perspective view showing another example of a swirler in the embodiments of the present invention;

FIG. 15 is a perspective view showing another example of a swirler in the embodiments of the present invention;

FIG. 16 is a cross-sectional view showing another example of an inflow casing in the embodiments of the present invention;

FIG. 17 is a perspective view showing another example of an inflow casing in the embodiments of the present invention;

FIG. 18 is a cross-sectional view of FIG. 17;

FIG. 19 is a perspective view showing another example of a fuel nozzle in the embodiments of the present invention;

FIG. 20 is a cross-sectional view of FIG. 19;

FIG. 21 is a perspective view showing an effect of the embodiments of the

present invention;

FIG. 22A is a partial enlarged cross-sectional view of FIG. 21;

FIG. 22B is an enlarged view of FIG. 22A;

FIG. 23 is a cross-sectional view showing a combustion apparatus according to a fifth embodiment of the present invention;

FIG. 24 is a cross-sectional view showing a combustion apparatus according to a sixth embodiment of the present invention;

FIG. 25 is a perspective view showing a combustion apparatus according to a seventh embodiment of the present invention;

FIG. 26 is a perspective view showing a combustion apparatus according to an eighth embodiment of the present invention;

FIG. 27 is a perspective view showing a combustion apparatus according to a ninth embodiment of the present invention;

FIG. 28 is a perspective view showing a combustion apparatus according to a tenth embodiment of the present invention;

FIG. 29 is a perspective view showing a combustion apparatus according to an eleventh embodiment of the present invention;

FIG. 30 is a perspective view showing a combustion apparatus according to a twelfth embodiment of the present invention;

FIG. 31 is a cross-sectional view showing a combustion apparatus according to a thirteenth embodiment of the present invention;

FIG. 32 is a perspective view showing a combustion apparatus according to a fourteenth embodiment of the present invention;

FIG. 33 is a cross-sectional view of FIG. 32;

FIG. 34 is a cross-sectional view showing a combustion apparatus according to a fifteenth embodiment of the present invention;

FIG. 35 is a cross-sectional view showing a combustion apparatus according to a sixteenth embodiment of the present invention;

FIG. 36 is a perspective view showing a case where a swirler is not used in the combustion apparatus of the second embodiment of the present invention;

FIG. 37 is a cross-sectional view of FIG. 36; and

FIG. 38 is a block diagram showing a case where a combustion apparatus according to the present invention is applied to a gas turbine generator.

Best Mode for Carrying Out the Invention

A combustion apparatus according to embodiments of the present invention will be described below with reference to FIGS. 5 through 38. In the following embodiments, the same parts are denoted by the same reference numerals and will not be described below repetitively.

First, a combustion apparatus according to a first embodiment will be described with reference to FIGS. 5 and 6. The combustion apparatus shown in FIG. 5 has an annular container 12 with one end (close end) 10 which is closed, an inflow casing 14, a swirler 16, and a fuel nozzle 18 provided on a rear face of the upper end (close end) 10 of the annular container 12. A plurality of air inflow portions 20 are formed at common pitches on a side surface of a peripheral portion (outer cylindrical portion 13 described below) of the annular container 12. Combustion air 22 flows through the air inflow portions 20 into the interior of the annular container 12, and inflow passages are formed by the air inflow portions 20, the inflow casing 14, and the swirler 16.

As shown in FIG. 6 in detail, the annular container 12 has an inner cylindrical portion 15 and an outer cylindrical portion 13, and is configured such that the inner cylindrical portion 15 and the outer cylindrical portion 13 are closed by the close end 10. A lower end of the annular container 12 serves as an opened outlet 26 for a combustion gas. A plurality of inner air inflow portions 30 are formed in the inner cylindrical portion 15 of the annular container 12 at positions above the air inflow portions 20 formed in the outer cylindrical portion 13.

The swirler 16 has guide vanes, which are not explicitly illustrated in FIGS. 5

and 6. For example, the same number of guide vanes as a plurality of air inflow portions 20 at the common pitches are disposed so as to twist and extend upward in oblique directions, not in normal directions with respect to a central axis. Inner ends of the guide vanes are connected to the vicinities of the air inflow portions 20. Other details of the swirler 16 will be described later.

The inflow casing 14 has an inner cylinder 34 disposed so as to form a predetermined gap portion 32 inside of the inner cylindrical portion 15 of the annular container 12, an outer cylinder 38 disposed so as to form a predetermined gap portion 36 outside of the outer cylindrical portion 13 of the annular container 12, an inner bottom member 40 connecting a lower end of the inner cylinder 34 to a lower end of the inner cylindrical portion 15 of the annular container 12, and an outer bottom member 42 connecting a lower end of the outer cylinder 38 to a lower end of the outer cylindrical portion 13 of the annular container 12.

Although the fuel nozzle 18 is not explicitly illustrated in FIGS. 5 and 6, for example, the fuel nozzle 18 can be provided by forming a large number of holes (nozzle holes) in a single hollow ring, or by attaching a large number of nozzle tips.

In the combustion apparatus thus constructed, combustion air 22 flows into the gap 36, which is formed by the outer cylinder 38 of the inflow casing 14 and the outer cylindrical portion 13 of the annular container 12, and then flows through the swirler 16 from the air inflow portions 20 into the annular container 12 upward in oblique directions by a blower or a compressor (not shown). Fuel 21 is injected through the fuel nozzle 18 into the interior of the annular container 12 by a fuel pump, a blower, or a compressor (not shown). The fuel 21 and the combustion air 22 are mixed and combusted in the annular container 12, and a combustion gas 24 is discharged from the open end 26 of the annular container 12.

In the first embodiment, as shown in FIG. 6, the combustion air 22 flows into the annular container 12 (upward in oblique directions from the air inflow portions 20) from positions which are located away from the close end 10 of the annular container 12 in an

axial direction of the annular container 12 by a predetermined distance with a velocity component in a direction opposite to a direction from the close end 10 to the open end 26 of the annular container 12 (outlet direction), and swirls in the annular container 12. Specifically, the air 22 flowing from the air inflow portions 20 into the annular container 12 forms a flow 28 having a velocity component in the direction of the central axis J of the annular container 12 from the open end 26 to the close end 10 and a velocity component to swirl in a circumferential direction of the annular container 12.

Simultaneously, fuel 23 is injected toward the inflow portions 20 for the combustion air in a direction from the close end 10 to the outlet 26 of the annular container 12 with a divergence angle α with respect to the central axis of the annular container 12 in a radial direction. Specifically, the fuel 23 is injected toward the air inflow portions 20 (inflow passages) with a velocity component in the direction of the central axis J from the close end 10 to the open end 26 and a velocity component directed radially outward.

Further, since air 22a flows from the inner air inflow portions 30 downward in oblique directions within the annular container 12, an inner wall of the inner cylindrical portion 15 of the annular container 12 is suitably cooled.

Although not shown in the drawings, an opening ratio, shapes, and pitches of the air inflow portions 20 in the side surface of the annular container 12 can be set arbitrarily. Further, although not shown in the drawings, a structure to deflect the flowing combustion air 22 may be provided on the inflow portions 20 for the combustion air 22 flowing into the annular container 12 as long as the flowing combustion air 22 has a velocity component in a direction opposite to the outlet 26.

In FIG. 6, the reference numeral 28 represents a swirling flow having a large velocity component in a direction opposite to the outlet 26, which is formed by the combustion air 22 flowing from the air inflow portions 20 and a combustion gas produced by combustion of mixture of the combustion air 22 and the fuel.

Next, a combustion apparatus according to a second embodiment will be

described with reference to FIGS. 7 and 8. FIGS. 7 and 8 show an embodiment of a combustion apparatus in which the annular container 12 in the first embodiment shown in FIGS. 5 and 6 is replaced with an annular container 112 having a structure in which an outer cylindrical portion 113 is constricted (a stepped structure). Air inflow portions 20 are formed at a stepped portion 100, i.e., a portion at which a diameter of the outer cylindrical portion 113 in the annular container 112 varies discontinuously.

A swirler 16 and an inflow casing 14 are substantially the same as those in a fourth embodiment described later. Accordingly, details of the swirler 16 and the inflow casing 14 will be described in the fourth embodiment.

According to the second embodiment thus constructed, combustion air 22 flows from the air inflow portions 20 into the annular container 112 so as to form a swirling flow 28 having a larger velocity component in a direction opposite to an outlet 26. Specifically, the air 22 flowing into the annular container 112 forms a flow 28 having a velocity component in a direction of a central axis J of the annular container 112 from the open end 26 to a close end 110 and a velocity component to swirl in a circumferential direction.

Simultaneously, fuel 23 is injected toward the air inflow portions 20 (inflow passages) with a velocity component in the direction of the central axis J from the close end 10 to the open end 26 and a velocity component directed radially outward.

In FIGS. 7 and 8, the cross-section change portion 100 of the outer cylindrical portion 113 in the annular container 112 is illustrated as being perpendicular to the axial direction of the annular container 112. However, the cross-section change portion 100 can have any desired angle. Further, although not shown in the drawings, an opening ratio, shapes, and pitches of the air inflow portions 20 can be set arbitrarily. Furthermore, although not shown in the drawings, a structure to deflect the flowing combustion air 22 may be provided on the air inflow portions 20. In FIG. 8, the reference numeral 115 represents an inner cylinder of the annular container 112, and the reference numeral 110 represents a close end of the annular container 112.

Next, a combustion apparatus according to a third embodiment of the present invention will be described with reference to FIGS. 9 and 10. FIGS. 9 and 10 show an embodiment of a combustion apparatus in which the annular container 112 in the second embodiment shown in FIGS. 7 and 8 is replaced with the following annular container 212 according to manufacturing requirements. In the annular container 212, an inner circumferential side surface (inner cylindrical portion) 215 of the annular container 212 is extended downstream at a cross-section change portion (stepped portion), and a secondary cylinder 200 (cylindrical member) is separately provided.

As is apparent from FIG. 10, the secondary cylinder 200 is small so that it can completely be received in an outer cylindrical portion 213 of the annular container 212. Specifically, the secondary cylinder 200 has a cross-sectional area smaller than that of the outer cylindrical portion 213 of the annular container 212. Thus, the secondary cylinder 200 is completely received within a virtual cylindrical shape that is an extension of the outer cylindrical portion 213.

An end portion 213a of the outer cylindrical portion 213 in the annular container 212 at the side of an open end 26 is connected to an outer circumferential surface of the secondary cylinder 200 at the side of a close end 210 by an annular connecting member 270. Air inflow portions 20 (inflow passages) are formed in the connecting member 270. On the other hand, the inner cylindrical portion 215 of the annular container 212 has a shape extended toward the open end 26 of the annular container 212 substantially coaxially with the secondary cylinder 200.

According to the third embodiment shown in FIGS. 9 and 10, since a combustion chamber is formed by the annular container 212, the secondary cylinder 200, and the connecting member 270, the combustion apparatus can readily be assembled.

In the third embodiment, air flowing from the inflow portions 20 into the annular container 212 forms a flow 28 having a velocity component in a direction of a central axis J of the annular container 212 from the open end 26 to the close end 210 and a velocity component to swirl in a circumferential direction of the annular container 212.

Simultaneously, fuel is injected toward the inflow portions 20 (inflow passages) with a velocity component in the direction of the central axis J from the close end 210 to the open end 26 and a velocity component directed radially outward.

The third embodiment shown in FIGS. 9 and 10 is configured so as to provide auxiliary air inflow ports 271 (additional inflow passage) on an inner side of the close end 210 near the inner cylindrical portion 215 and inwardly in a radial direction of a fuel nozzle 18, particularly as shown in FIG. 10, to allow air to flow in the direction of the central axis J of the annular container 212 (as shown by arrows 272). With this arrangement, the air 272 flows along an inner wall surface 215a of the inner cylindrical portion 215 to efficiently cool the inner wall surface 215a of the inner cylindrical portion 215. In FIG. 9, the auxiliary air inflow ports 271 are represented by arrows.

The auxiliary air inflow ports 271 can be applied not only to the third embodiment shown in FIGS. 9 and 10, but also to the first embodiment and the second embodiment shown in FIGS. 5 through 8. Similarly, an arrangement for injected air flows 271 from the auxiliary air inflow ports 271 to cool the inner wall surface 215a of the inner cylindrical portion can be applied to other embodiments shown in FIGS. 11 through 38, which will be described later.

Next, a combustion apparatus according to a fourth embodiment will be described with reference to FIGS. 11 and 12. FIGS. 11 and 12 show an embodiment of a combustion apparatus in which the annular container 112 in the second embodiment shown in FIGS. 7 and 8 is replaced with the following annular container 312 according to manufacturing requirements. In this embodiment, the annular container 312 is divided into a secondary annular container (annular member) 402, a first connecting member 270, and a second connecting member 470 at a cross-section change portion (stepped portion) 400.

In FIG. 12, the reference numeral 404 represents an inner cylindrical portion of the secondary annular container 402, and the reference numeral 406 represents an outer cylindrical portion of the secondary annular container 402. As is apparent from FIG. 12,

the outer cylindrical portion 406 of the secondary annular container 402 is small so that it can completely be received in an outer cylindrical portion 213 of the annular container 312. Specifically, the outer cylindrical portion 406 of the secondary annular container 402 has a cross-sectional area smaller than that of the outer cylindrical portion 213 of the annular container 312. Thus, the outer cylindrical portion 406 of the secondary annular container 402 is completely received within a virtual cylindrical shape that is an extension of the outer cylindrical portion 213.

An end portion 213a of the outer cylindrical portion 213 in the annular container 312 at the side of an open end 26 is connected to an outer circumferential surface of the outer cylindrical portion 406 of the secondary annular container 402 at the side of a close end 210 by the first annular connecting member 270. Air inflow portions 20 (inflow passages) are formed in the connecting member 270. On the other hand, the inner cylindrical portion 404 of the secondary annular container 402 is located on an extension of an inner cylindrical portion 215 of the annular container 312. The inner cylindrical portion 404 of the secondary annular container 402 is connected to the inner cylindrical portion 215 of the annular container 312 by the second connecting member 470.

In FIGS. 11 and 12, the inner cylindrical portion 215 of the annular container 312 and the inner cylindrical portion 404 of the secondary annular container 402 are illustrated as having the same diameter. However, the diameter of the inner cylindrical portion 215 in the annular container 312 may be different from the diameter of the inner cylindrical portion 404 in the secondary annular container 402.

According to the fourth embodiment shown in FIGS. 11 and 12, since a combustion chamber is formed by the annular container 312, the secondary annular container 402, and the first connecting member 270 and the second connecting member 470 which connect the annular container 312 and the secondary annular container 402 to each other, the combustion apparatus can readily be assembled.

Next, the swirler 16 will be described in detail with reference to FIGS. 13 to 15. As shown in FIG. 13, the swirler 16 is generally configured such that swirl vanes 54 for

deflecting a flow are disposed between the inner cylinder 50 and the outer cylinder 52 to form air introduction passages 56. Further, as shown in another example of FIG. 14, the swirler 16 may have air introduction passages 56a opened in an annular member 58 for deflecting a flow. In this case, the shape of the air introduction passages 56a may be set arbitrarily. Alternatively, as shown in still another example of FIG. 15 which achieves the same effects as the above swirler 16, air introduction passages 56b divided for each air inflow portion 20 in the connecting member 270 may be attached to the connecting member 270.

Further, in a structure shown in FIGS. 13 and 14, the swirler 16 may also serve as a connecting member. Specifically, in the example shown in FIG. 13, the inner cylinder 50 and the outer cylinder 52 may be dispensed with. The secondary cylinder 200 (see FIGS. 9 and 10) in the third embodiment and the container 212 (see FIGS. 9 and 10) may be connected to each other by swirl vanes 54. The secondary annular container 402 (see FIGS. 11 and 12) in the fourth embodiment and the annular container 312 may be connected to each other by swirl vanes 54. In either case, the swirl vanes 54 can also serve as a connecting member 270. In the example shown in FIG. 14, the annular member 58 can also serve as a connecting member 270 (FIGS. 9 to 12).

In FIGS. 9, 10, 11, and 12, the first connecting member 270 is illustrated as being perpendicular to the axial direction of the annular container 312 and the secondary annular container 402. However, the first connecting member 270 may have any desired angle. Although not shown in the drawings, an opening ratio, shapes, and pitches of the air inflow portions 20 can be set arbitrarily. Furthermore, the swirler 16 is illustrated as having an axial flow shape. However, the swirler 16 may have a mixed flow shape in which combustion air 22 also flows from a periphery of the swirler 16. Further, although not shown in the drawings, a structure to deflect the flowing air 22 in a radial direction may be provided on the air inflow portions 20.

As shown in FIG. 16, the inflow casing 14 may comprise a back flow type inflow casing 14b, which is suitable for a centrifugal compressor and a turbine.

When an inner side of the annular container 312 (including the annular containers 12, 112, and 212) is formed by a heat resistant material, as shown in FIGS. 17 and 18, the inflow casing 14c may be integrated with the annular container 312 if it is not necessary to form air inflow holes 20 in the inner side of the annular container 312. In this case, it is not necessary to provide a dual structure in which the inflow casing 14c encloses a portion of the annular container 312 from the air inflow portions 20 to the close end 210 or the entire annular container 312. Accordingly, a fuel nozzle 18 or an ignition device, which is not shown in the drawings, can be attached without extending through the inflow casing 14c. Specifically, it is possible to simplify the structure and achieve cost reduction. (In this case, it is desirable that an exposed annular container 312 is insulated by a heat insulator.)

With regard to the casing, although not shown in the drawings, when the divided air introduction passages 56b as shown in FIG. 15 serve as the swirler 16, for example, extension pipes may be connected to the air introduction passages 56b, and an inflow pipe to join the extension pipes may be provided instead of the inflow casing 14. This also holds true when other air introduction passages are provided.

With regard to the fuel nozzle, as shown in FIGS. 19 and 20, a plurality of nozzles 18a may be disposed substantially coaxially with each other instead of a single annular fuel nozzle 18 (FIGS. 5 through 12). This case can also achieve the same effects as a single nozzle as long as fuel is injected from the close end 210 of the annular container 312 toward the outlet 26 in the form of a jet, or a cone having a relatively small divergence angle, or a sector so as to be directed to the inflow portions 20 for the combustion air with a radially outward angle with respect to the central axis of the annular container 312. Particularly, a plurality of nozzles 18a are effective in a large-sized combustion apparatus having a difficulty in applying a single nozzle.

The aforementioned equivalent structures of the container, the swirler, the casing, and the fuel nozzle can be applied to the first to fourth embodiments and all of the following embodiments.

Effects of the aforementioned embodiments will be described in greater detail using the example of the fourth embodiment shown in FIGS. 21, 22A, and 22B.

In FIGS. 21 and 22A, fuel 21 is injected from the fuel nozzle 18 with a radially outward divergence angle with respect to the central axis J (see FIG. 22A) of the annular container 312. Specifically, the fuel 21 is injected toward the air inflow portions 20 with a velocity component in the direction of the central axis J from the close end 210 to the open end 26 and a velocity component directed radially outward.

Now is considered some fuel tracks 23a and 23b (see FIG. 21) of the fuel injected with a divergence angle with respect to the axial direction of the annular container 312. In FIG. 22A, combustion air 22 flows into the gap 36, which is formed by the outer cylinder 38 of the inflow casing 14 and the outer cylindrical portion 213 of the annular container 312, by a blower or a compressor, which is not shown in the drawings, and then flows from air inflow portions formed in the connecting member 270, which is not shown in the drawings, through the swirler 16 into the annular container 312. The combustion air 22b flowing into the annular container 312 swirls and goes upstream in a direction opposite to the outlet 26 within the annular container 312, and intersects one track 23a at a location 25 (see FIG. 21). In other words, the air 22b flowing from the air inflow portions to the annular container 312 forms a flow 28 which has a velocity component in the direction of the central axis J of the annular container 312 from the open end 26 to the close end 210 and swirls in a circumferential direction of the annular container 312.

In a case of liquid fuel, the diameter of particles in fuel 21 passing through the fuel track 23a becomes small at the location 25 because the fuel has been evaporated to some extent. The speed of the fuel 21 is lower than that near an outlet of the nozzle 18 because the fuel has moved in an air flow. Because the velocities of the fuel 21 and the combustion air 22b are opposed to each other, the fuel 21 rides on a flow of the combustion air 22b. Thus, the fuel 21 is ignited and combusted to form a flame.

The combustion air 22b further swirls and goes upstream in a direction opposite

to the outlet within the annular container 312 so as to become a combustion gas 24b having a high temperature and a low oxygen concentration. As the combustion gas 24b comes close to the close end 210 of the annular container 312, the combustion gas 24b changes its direction so as to be close to the central axis of the annular container 312. The combustion gas changes its direction into a direction of the outlet 26 near the inner cylinder 215 of the annular container 312 and crosses the fuel track 23b at a location 27. Specifically, burnt gas recirculation occurs. The fuel track 23b crossed by the combustion gas 24a may be the same as the fuel track 23a.

At the location 27 (see FIG. 21), the combustion gas 24b having a high temperature and a low oxygen concentration does not ignite the fuel but pre-evaporates the fuel. The evaporated fuel flows together with the combustion gas 24b. Although the combustion gas 24b has a high temperature, it has a low oxygen concentration. Thus, the combustion gas 24b suppresses a combustion rate. Accordingly, the evaporated fuel is not ignited immediately but is premixed. After a certain period of time, the evaporated fuel is ignited and combusted, and the combustion gas 24b becomes a combustion gas 24 having a higher temperature and a lower oxygen concentration, which is discharged from the outlet 26.

Unlike conventional technology, in the fourth embodiment, it is important that actual ignition and combustion at a low oxygen concentration by first bringing most of fuel into contact with the combustion gas 24b, not first bringing most of fuel into contact with the combustion air 22 can be achieved.

In the embodiment of the present invention as illustrated in FIGS. 21, 22A, and 22B, if less evaporation of the fuel should be caused near a root of the fuel track 23, more fuel is mixed with the combustion air 22b at a tip of the fuel track 23 to increase the temperature of the combustion gas 24b. Thus, evaporation is promoted at the root of the fuel track 23. Specifically, a feedback effect is obtained with respect to the amount of evaporation. Accordingly, even if conditions of fuel injection are changed, the effects according to the embodiments of the present invention (as illustrated in FIGS. 21, 22A,

and 22B) can stably be obtained.

In a case of gaseous fuel, the fuel is injected so as to penetrate a flow of air in a jet state and reach the location 25 (before the fuel jet loses its momentum) while its peripheral portion is partially mixed with the air. As with the case of liquid fuel, the combustion air 22b swirls and goes upstream in a direction opposite to the outlet 26 within the annular container 312 and intersects the fuel track 23a, so that the combustion air 22b is mixed with the fuel 21 so as to become a combustion gas 24b having a high temperature and a low oxygen concentration.

As the combustion gas 24b comes close to the close end 210 of the annular container 312, the combustion gas 24b changes its direction so as to be close to the central axis of the annular container 312. The combustion gas 24b turns its direction near the inner cylindrical portion 215 and crosses the fuel track 23b at the location 27. Thus, burnt gas recirculation occurs. Although the combustion gas 24b has a high temperature, it has a low oxygen concentration. Thus, the combustion gas 24b suppresses a combustion rate. Accordingly, the fuel is not ignited immediately but is premixed. After a certain period of time, the fuel is ignited and combusted.

The most fundamental effect according to the embodiments of the present invention (as illustrated in FIGS. 21, 22A, and 22B) is as follows. The direction of a flow of air is changed in the combustion apparatus. The tracks of the combustion air and the fuel are not the same in the combustion apparatus. The track of the air and the track of the fuel intersect each other two times. Further, the fuel and the air are mixed with each other so that the air first intersects the fuel track near its tip and then intersects the fuel track in a region from the root of the fuel track to the vicinity of the tip. Thus, burnt gas recirculation is positively controlled and generated.

In the embodiments of the present invention (as illustrated in FIGS. 21, 22A, and 22B), a flow in the combustion apparatus is shown in FIG. 22B within a cross-section passing through the central axis of the annular container 312. The combustion air 22 flowing into the annular container 312 is schematically illustrated as divided parts 22a,

22b, 22c, 22d, and 22e according to positions.

Most 22b, 22c, and 22d of the combustion air 22 flowing into the annular container 312 collide with the fuel track, respectively, and thus become combustion gases 24b, 24c, and 24d. These gases go upstream deeply within the annular container 312 and intersect the fuel track 23 again. As an inflow position of the combustion air is farther away from the outer cylindrical portion 213 of the annular container 312, the combustion air goes upstream only to a shallower location and then turns its direction. Of the combustion air 22 flowing into the annular container 312, the combustion air 22a flowing from the location closest to an inner surface of the outer cylinder 213 in the container 312 goes upstream to the deepest location in the container 312 without colliding with the fuel 21. As the combustion air 22a goes upstream, it is mixed with the combustion gas 24b so as to become a combustion gas 24a. Thus, the combustion gases 24a, 24b, 24c, and 24d uniformly cross the fuel track 23. Effects of the burnt gas recirculation can be achieved most effectively.

Another fundamental effect according to the embodiments of the present invention as illustrated in FIGS. 21, 22A, and 22B is that the combustion gas uniformly crosses the track of the fuel. With these effects, in the combustion apparatus according to the embodiments of the present invention, as shown in FIG. 22A, there are formed two flames of a second annular flame 60 near the inner cylindrical portion 215 of the annular container 312 and a first annular flame 62 near the outer cylindrical portion 213 but away from an inner wall of the outer cylinder 213 of the annular container 312.

The first annular flame 62 has a long residence time in the annular container 312 because the combustion air 22 swirls. The first annular flame 62 becomes uniform because it is well mixed in the circumferential direction. An increase of temperature of the combustion air and a reduction of oxygen concentration, which are caused by the fact that the combustion air 22 and the fuel 21 (see FIG. 21) are opposing each other and by the fact that a combustion gas having a high temperature is supplied to the combustion air that is to be mixed with the fuel from the second annular flame 60 with turbulent

diffusion, promote evaporation of the fuel while suppressing ignition of the fuel. Accordingly, the stability of the flame is enhanced.

Further, since the combustion gases 24a, 24b, 24c, and 24d of the first annular flame 62 cross the fuel track 23, the first annular flame 62 serves as a reliable ignition source to enhance the stability of the second annular flame 60. Combustion occurs with the combustion gas having a high temperature and a low oxygen concentration in the second annular flame 60. Accordingly, pre-evaporation combustion, premixed combustion, and slow combustion are achieved. Unlike usual diffusive combustion, no areas having a theoretical mixture ratio and a high temperature are produced locally in this combustion. The combustion is uniform with a low maximum flame temperature. An average flame temperature is lowered due to the heat capacity of an inert gas in the combustion gas. Accordingly, generation of thermal NOx is suppressed.

Further, the following is advantageous in cooling. Of the combustion air 22 flowing into the annular container 312 as shown in FIG. 22, the combustion air 22a flowing from the location closest to the inner circumferential surface of the outer cylindrical portion 213 of the annular container 312 goes upstream deepest within the annular container 312 without colliding with (the fuel 21 or) the fuel track 23. As the combustion air goes upstream, it is mixed with the combustion gas 24b so as to become the combustion gas 24a. Since the combustion gas 24a has a relatively low temperature, the inner surface of the annular container 312 is protected from being overheated.

Meanwhile, the combustion air 22e flowing from the farthest location away from an inner surface of the outer cylindrical portion 213 of the annular container 312 into the annular container 312 turns at a location closer to the outlet 26 than the reaching point of the fuel 21 and flows toward the outlet 26. Accordingly, the combustion air 22e does not become a combustion gas but is mixed with the combustion gas of the main flame (second annular flame) 60 gradually from a portion away from the inner surface 406a of the outer cylinder 406 of the secondary annular container 402.

However, the turned combustion air 22e has a relatively low temperature at a

portion closest to the inner surface 406a of the outer cylinder 406 of the secondary annular container 402. Thus, the inner circumferential surface 406a of the outer cylinder 406 of the secondary annular container 402 is protected from a high temperature of the main flame 60. The combustion gas having a high temperature passes through surfaces of an inner side portion 215 of the annular container 312 and an inner side (inner cylinder 404) of the secondary annular container 402. Accordingly, air holes 30 may be provided in the inner side portion of the annular container 312 and the inner circumferential surface 404a of the inner cylinder 404 of the secondary annular container 402, as needed, for injecting cooling air in a jet state or along the wall surface for cooling. When the inner side portion of the annular container 312 and the surface 404a of the inner cylinder 404 of the secondary annular container 402 are made of a heat resistant material, no air inflow holes 30 may be provided in the inner side portion of the annular container 312 and the inner circumferential surface 404a of the inner cylinder 404 of the secondary annular container 402.

The aforementioned effects in the embodiment of the present invention are applied not only to the fourth embodiment shown in FIGS. 21, 22A, and 22B, but also to the first embodiment to the third embodiment and other embodiments following the fifth embodiment.

Further, the following is advantageous in structure. Since the combustion chamber is divided into the annular container 312 and a downstream structure (secondary annular container), the annular container 312 can readily be taken out. As compared to the conventional technology, disassembly, replacement, and adjustment of the combustion apparatus are facilitated to improve easiness of maintenance.

Next, a combustion apparatus according to a fifth embodiment, which is compatible with the fourth embodiment, will be described with reference to FIG. 23. FIG. 23 shows an embodiment of a combustion apparatus having an annular container 512 in which the close end 510 of the annular container is formed by a curved surface in which a cross-sectional curve Lr is formed by a free-form arc having a nonuniform

curvature, unlike the first embodiment to the fourth embodiment.

In the example shown in FIG. 23, most parts of the annular container 512 are formed by the close end 510 having a curved surface. A secondary annular container 402 is connected to an extremely short inner cylindrical portion 515 of the annular container 512 via a second connecting member 470 and to an outer cylindrical portion 513 via a connecting member 270.

The combustion apparatus in the fifth embodiment can also achieve the same effects as described in the fourth embodiment. Since the close end 510 of the annular container 512 is formed by a curved surface, it is possible to facilitate manufacturing and reduce cost in a case where the annular container 512 is made of a heat resistant material such as ceramics, particularly, for the purpose of a high combustion temperature. Further, since the combustion chamber is divided into the annular container 512 and a downstream structure (secondary annular container 402), the annular container 512 can readily be taken out. As compared to the conventional technology, disassembly, replacement, and adjustment of the combustion apparatus are facilitated to improve easiness of maintenance. The annular container 512 partially including a curved surface in the fifth embodiment may be applied to the first embodiment to the third embodiment.

Next, a combustion apparatus according to a sixth embodiment will be described with reference to FIG. 24. The combustion apparatus shown in FIG. 24 is an application of the fourth embodiment shown in FIGS. 11 and 12. That is, auxiliary air holes are formed in the outer cylindrical portion of the annular container in the fourth embodiment. Specifically, in the embodiment of FIG. 24, the combustion apparatus in the sixth embodiment has a plurality of auxiliary air holes 619 formed in an outer cylindrical portion 613 near the close end 610 of the annular container 612.

The combustion air 22d flowing through a plurality of auxiliary air holes 619 thus formed in the outer cylindrical portion 613 near the close end 610 flows centrally into the annular container 612 in a jet state. Accordingly, the combustion gas 24b therearound is induced so as to promote a flow directed from the outer area (outer

cylindrical portion) 613 of the annular container 612 to the inner area (inner cylindrical portion) 615 near the close end 610 of the container 612. The swirling and flowing combustion gas 28 can be introduced into a portion near the inner area (inner cylindrical portion) 615 of the annular container 612 at a location near the close end 610 of the annular container 612 and recirculated toward the fuel track 23. The auxiliary air holes 619 in the sixth embodiment may be applied to the first embodiment, the second embodiment, and the third embodiment.

Next, a combustion apparatus according to a seventh embodiment will be described with reference to FIG. 25. FIG. 25 shows an embodiment of the combustion apparatus in which a plurality of guide vanes 11 are provided as a flow adjusting structure inside of the close end 210 of the annular container 312 in the fourth embodiment (see FIGS. 11 and 12). Such guide vanes 11 can achieve the same effects as the auxiliary air holes 619 in the sixth embodiment (see FIG. 24). This embodiment is substantially the same as the fourth embodiment except that a plurality of guide vanes 11 are provided as a flow adjusting structure inside of the close end 210 of the annular container 312. Further, the guide vanes 11 can also be applied to the first embodiment to the third embodiment and the sixth embodiment.

Next, a combustion apparatus according to an eighth embodiment will be described with reference to FIG. 26. FIG. 26 shows an embodiment of the combustion apparatus in which a plurality of guide vanes 11a are provided as a flow adjusting structure on an inner surface of the outer cylindrical portion 213 of the annular container 312 of the fourth embodiment and near the close end 210 to achieve the same effects as the auxiliary air holes 619 in the sixth embodiment (see FIG. 24). This embodiment is substantially the same as the fourth embodiment except that a plurality of guide vanes 11a are provided as a flow adjusting structure on the inner surface of the outer cylindrical portion 213 of the annular container 312 and near the close end 210. Further, the guide vanes 11a can also be applied to the first embodiment to the third embodiment and the sixth embodiment. Furthermore, the flow adjusting structure shown in the seventh

embodiment and the eighth embodiment may be both provided.

Next, a combustion apparatus according to a ninth embodiment will be described with reference to FIG. 27. In the combustion apparatus shown in FIG. 27, the similar guide vanes to the seventh embodiment and the eighth embodiment are applied to the fifth embodiment shown in FIG. 23. Specifically, in the illustrated embodiment, guide vanes 11b are formed so as to extend along an inner curved surface of the close end 510 of the annular container 512, which is formed by a curved surface, substantially to a top of the close end 510.

Each of the guide vanes 11, 11a, and 11b shown in the seventh embodiment to the ninth embodiment has a function to suppress a swirling flow and regulate the flow in a radial direction near the close end 210 or 510 of the annular container 212 or 512. As a result, the swirling and flowing combustion gas 24a (not shown) can be introduced into an inner portion of the close end 210 or 510 of the annular container 212 or 512 and smoothly recirculated toward the fuel track 23, as with the fifth embodiment.

A tenth embodiment to a twelfth embodiment, which are further developments of the seventh embodiment to the ninth embodiment, will be described with reference to FIGS. 28 through 30.

First, in the tenth embodiment shown in FIG. 28, the guide vanes 11 as a flow adjusting structure in the seventh embodiment shown in FIG. 25 are optimized. Specifically, guide vanes 11c in the tenth embodiment are curved in an arc form such that the shape of the guide vanes 11 in the seventh embodiment shown in FIG. 25 spirals toward the inner cylinder 215 of the annular container 312 so as to facilitate the flow of the combustion air flowing into the central portion of the annular container 312. The guide vanes 11c can also be applied to the first embodiment to the third embodiment and the sixth embodiment. Further, the guide vanes 11c can be used together with the guide vanes 11a in the eighth embodiment.

In the eleventh embodiment shown in FIG. 29, the guide vanes 11a as a flow adjusting structure in the eighth embodiment shown in FIG. 26 are optimized.

Specifically, guide vanes 11d in the eleventh embodiment are deformed such that the shape of the guide vanes 11a in the eighth embodiment shown in FIG. 26 is inclined along an inner wall of the outer cylindrical portion 312 of the annular container 212 while upper ends of the guide vanes 11d are directed in a vertical direction in the illustrated example. The guide vanes 11d can also be applied to the first embodiment to the third embodiment and the sixth embodiment. Further, the guide vanes 11d can be used together with the guide vanes 11 in the seventh embodiment or the guide vanes 11c shown in the tenth embodiment.

In the twelfth embodiment shown in FIG. 30, the guide vanes 11b as a flow adjusting structure in the ninth embodiment shown in FIG. 27 are optimized. Specifically, guide vanes 11e in the twelfth embodiment are deformed such that the shape of the guide vanes 11b in the ninth embodiment shown in FIG. 27 is inclined along a curved inner wall of the outer cylindrical portion 513 of the annular container 512 while upper ends of the guide vanes 11e are directed in a vertical direction in the illustrated example.

In the tenth embodiment to the twelfth embodiment, the flow adjusting structure (guide vanes) 11c, 11d, or 11e has an effect to centrally deflect a flow of the swirling combustion gas 24a (not shown) positively and more smoothly. Thus, the swirling and flowing combustion gas 24a can be more smoothly introduced into the inner area (inner cylindrical portion) 215 or 515 of the annular container 212 or 512 and recirculated toward the fuel track 23 near the close end 210 or 510 of the annular container 212 or 512.

Even if the detail of the shape of the flow adjusting structure is changed, it is substantially equivalent to the above flow adjusting structure as long as it has an effect to deflect the swirling flow into a centrally directed flow. Further, the flow adjusting structure may include plate-like or stand-like objects attached to the annular container 212 or 512, or may include grooves formed in the inner surface of the annular container 212 or 512.

Next, a combustion apparatus according to a thirteenth embodiment, which is an application of the fourth embodiment, will be described with reference to FIG. 31. In this combustion apparatus, auxiliary fuel nozzles 702 for accessorily injecting fuel are provided on an inner surface of the outer cylindrical portion 713 of the annular container 712 which has the inner cylindrical portion 715 and the outer cylindrical portion 713. These fuel nozzles 702 are positioned slightly away from the inflow portions 20 for the combustion air 22 toward the close end 710.

Fuel injected from the auxiliary fuel nozzles 702 may be the same as or different from the fuel injected from the main fuel nozzle 18. Even if the fuel 21 has a difficulty to reach the inflow portions 20 (not shown) for the combustion air 22 because the combustion apparatus has a large size or a limited injection pressure in a case of gaseous fuel, injection of the same fuel from the auxiliary fuel nozzles 702 achieves combustion with suppressing generation of thermal NOx due to burnt gas recirculation, as with the second embodiment.

Further, liquid/gas multi fuel combustion can be achieved with a simple arrangement by injecting liquid fuel from the fuel nozzle 18 and injecting gaseous fuel from the auxiliary fuel nozzles 702. Turndown performance can further be improved by the auxiliary fuel nozzles 702. Further, when fuel having such a low heating value that stable combustion is difficult is used, particularly when fuel like waste liquid, which has a low heating value, is used, injection of fuel having a low heating value or waste liquid from the fuel nozzle 18 and injection of fuel having good combustibility from the auxiliary fuel nozzles 702 produce pre-evaporated and premixed fuel by burnt gas recirculation to achieve combustion with suppressing generation of thermal NOx, as with the fourth embodiment.

In FIG. 31, the auxiliary fuel nozzles 702 include a plurality of nozzles provided on the inner surface of the outer cylindrical portion 713 of the annular container 712. As another arrangement, a single ring having a large number of injection holes (not shown) may be disposed on the inner surface of the outer cylindrical portion 713 of the annular

container 712.

The auxiliary fuel nozzles 702 in the thirteenth embodiment are also applicable to the first embodiment to the third embodiment and the fifth embodiment to the twelfth embodiment.

When the present invention is applied to a combustion apparatus in a gas turbine, the aforementioned embodiments (the first embodiment to the thirteenth embodiment) are regarded as a primary combustion zone, and additional air inflow portions are provided downstream of the outlet 26. Meanwhile, in a combustion apparatus of a gas turbine, many technologies have been known to add air downstream of a primary combustion zone in order to prevent a lowered combustion efficiency which causes discharge of unburnt components or an increased generation of NOx. Accordingly, when the present invention is applied to a gas turbine, known technology can be applied to the aforementioned embodiments. Thus, many applications can be obtained within the concept of the present invention. Not all of such applications can be explained, and some examples of such applications will be described below.

A combustion apparatus in a gas turbine according to a fourteenth embodiment will be described with reference to FIGS. 32 and 33. In the fourteenth embodiment shown in FIGS. 32 and 33, the combustion apparatus in the aforementioned fourth embodiment is applied to a gas turbine combustion apparatus.

As compared to the fourth embodiment, in the gas turbine combustion apparatus shown in FIGS. 32 and 33, the secondary annular container is replaced with a secondary annular container 802 which is extended toward the outlet and has air holes 814 and 814b formed at proper positions. Further, the secondary annular container 802 is enlarged (808) in cross-section at a downstream portion, which is arbitrary. Furthermore, although the secondary annular container 802 is integrally formed including the outlet 26, it may be divided for manufacturing requirements.

Secondary and dilution air 818 flows through the air holes 814 and 814b formed as a plurality of stages in the secondary annular container 802. As with the fourth

embodiment, burnt gas recirculation occurs uniformly along a fuel track 23 in the primary combustion zone 816 to perform combustion with a combustion gas having a high temperature and a low oxygen concentration. Accordingly, pre-evaporation combustion is achieved in a case of liquid fuel, and premixed combustion and slow combustion are achieved in a case of gaseous fuel or liquid fuel. Uniform combustion with a low maximum flame temperature can be performed (unlike usual diffusive combustion in which areas having a theoretical mixture ratio and a high temperature are produced locally in the combustion). An average flame temperature is lowered due to the heat capacity of an inert gas in the combustion gas. Accordingly, generation of thermal NOx is suppressed. The inner wall surface of the outer cylinder 806 to the uppermost secondary air holes 814 of the secondary annular container 802 is cooled by a portion of the primary air 817 as with the fourth embodiment.

Cooling air holes 814b may optionally be formed in a wall surface of the outer cylinder 806 of the secondary annular container 802. A gas having a high temperature passes near an inner side portion 215 of the annular container 312 and a surface of the inner cylinder 804 in the secondary annular container 802. Accordingly, air holes may be provided in the inner side portion 215 of the annular container 312 and the inner cylinder 804 of the secondary annular container 802 so as to inject cooling air in a jet state or along the wall surface as needed. When the inner side portion 215 of the annular container 312 and the inner cylinder 804 of the secondary annular container 802 are made of a heat resistant material, no air inflow holes may be formed in the inner side portion 312 of the annular container 212 and the inner cylinder 804 of the secondary annular container 802.

Further, because the stability of the primary combustion zone 816 is high, a ratio of a flow rate of the primary air 817 to a total flow rate of air can be increased to perform leaner primary combustion so as to lower a combustion temperature. Accordingly, it is possible to further suppress generation of thermal NOx. Further, since the combustion chamber is divided into the annular container 312 and a downstream structure (secondary

annular container 802), the annular container 312 can readily be taken out. As compared to the conventional technology, disassembly, replacement, and adjustment of the combustion apparatus are facilitated to improve easiness of maintenance.

When the first embodiment to the third embodiment and the sixth embodiment to the thirteenth embodiment are applied to a gas turbine combustion apparatus instead of the fourth embodiment, it is possible to achieve the operations and effects of the fourteenth embodiment. At that time, the operations and effects of the first embodiment to the third embodiment and the sixth embodiment to the thirteenth embodiment can also be achieved.

Next, a gas turbine combustion apparatus to a fifteenth embodiment will be described with reference to FIG. 34. In the fifteenth embodiment shown in FIG. 34, the combustion apparatus in the fifth embodiment is applied to a gas turbine combustion apparatus. As compared to the fifth embodiment, in the gas turbine combustion apparatus shown in FIG. 34, the secondary annular container is replaced with a secondary annular container 802 which is extended toward the outlet 26 and has air holes 814 and 814b formed at proper positions. Further, the secondary annular container 802 is enlarged in cross-section at a downstream portion, which is arbitrary. Furthermore, although the secondary annular container 802 is integrally formed including the outlet 26, it may be divided for manufacturing requirements. Secondary and dilution air 818 flows through the air holes 814 and 814b formed as a plurality of stages in the secondary annular container 802.

As with the fifth embodiment, burnt gas recirculation occurs uniformly along a fuel track 23 in the primary combustion zone 816 to perform combustion with a combustion gas having a high temperature and a low oxygen concentration. Accordingly, pre-evaporation combustion is achieved in a case of liquid fuel, and premixed combustion and slow combustion are achieved in a case of gaseous fuel or liquid fuel. Uniform combustion with a low maximum flame temperature can be performed (unlike usual combustion in which areas having a theoretical mixture ratio and

a high temperature are produced locally in the combustion). An average flame temperature is lowered due to the heat capacity of an inert gas in the combustion gas. Accordingly, generation of thermal NOx is suppressed. The inner wall surface of the outer cylinder 806 to the uppermost secondary air holes 814 of the secondary annular container 802 is cooled by a portion of the primary air 817 as with the fifth embodiment.

Cooling air holes 814b may optionally be formed in a wall surface of the outer cylinder 806 of the secondary annular container 802 as shown in FIG. 34. A gas having a high temperature passes near an inner side of the annular container 512 and an inner surface of the inner cylinder 804 in the secondary annular container 802. Accordingly, air holes 814 may be provided in the inner circumferential surface of the annular container 512 and the inner cylinder 804 of the secondary annular container 802 so as to inject cooling air in a jet state or along the wall surface as needed. When the annular container 512 and the inner cylinder 804 of the secondary annular container 802 are made of a heat resistant material, no air inflow holes may be formed in the annular container 512 and the inner cylinder 804 of the secondary annular container 802.

Further, because the stability of the primary combustion zone 816 is high, a ratio of a flow rate of the primary air 817 to a total flow rate of air can be increased to perform leaner primary combustion so as to lower a combustion temperature. Accordingly, it is possible to further suppress generation of thermal NOx. Since the close end 510 of the annular container 512 is formed by a domelike curved surface, it is possible to facilitate manufacturing and reduce cost in a case where the annular container 512 is made of a heat resistant material such as ceramics, particularly, for the purpose of a high combustion temperature. Further, since the combustion chamber is divided into the annular container 512 and a downstream structure (secondary annular container 802), the annular container 512 can readily be taken out. As compared to the conventional technology, disassembly, replacement, and adjustment of the combustion apparatus are facilitated to improve easiness of maintenance.

Next, a gas turbine combustion apparatus to a sixteenth embodiment will be

described with reference to FIG. 35. The sixteenth embodiment shown in FIG. 35 is an application of the aforementioned fourteenth embodiment. Specifically, a secondary swirler 815 is used instead of the air holes at a mixing portion of secondary air 818 in the combustion apparatus of the fourteenth embodiment shown in FIG. 31. Air holes 814 are formed in the inner cylinder 804 of the secondary annular container 802, and air holes 814b are formed in the outer cylinder 806.

By forming a swirling flow of the secondary air 818 with the secondary swirler 815, it is possible to promote mixing in a secondary zone. When air is to be added downstream of a primary combustion zone, known technology can be employed in order to prevent a lowered combustion efficiency which causes discharge of unburnt components or an increased generation of NOx. Thus, various applications can be obtained within the concept of the present invention.

In the aforementioned embodiments, air is supplied into the combustion chamber while being swirled. FIGS. 36 and 37 show an example in which air is supplied without being swirled. Instead of the swirler, the combustion apparatus shown in FIGS. 36 and 37 uses introduction passages 17 for supplying air so as to have only a velocity component in a direction facing a flow of fuel with respect to a direction of a central axis of the combustion chamber at air inflow portions 20. With this arrangement, the following flow state can be formed. A track of an air flow and a track of a fuel flow are not the same. The track of the air flow and the track of the fuel flow intersect each other two times. The first intersection of the air flow with the track of the fuel flow is located near a tip of the fuel track, and the second intersection of the air flow with the track of the fuel flow is located in a region from a root of the track of the fuel flow to the vicinity of the tip.

FIGS. 36 and 37 show an arrangement in which no swirler is used in the second embodiment. No swirler may be used in the first and third to sixteenth embodiments. However, in the first to sixteenth embodiments using a swirler, the air flow becomes a swirling flow swirling along an inner wall surface of the combustion apparatus, so that

centrifugal forces are applied to the air flow. Accordingly, the air flow can go upstream smoothly along the inner surface of the outer circumferential surface of the combustion apparatus by a long distance before the air flow changes its direction to a direction of the outlet of the combustion apparatus. Specifically, the arrangement shown in the first to sixteenth embodiments can form the aforementioned flow state more efficiently as compared to the arrangement representatively shown in FIGS. 36 and 37.

Next, an example in which a combustion apparatus of the aforementioned embodiments is applied to a gas turbine generator will be described with reference to FIG. 38. The gas turbine generator shown in FIG. 38 has a gas turbine apparatus 900 and a power generator 902.

The gas turbine apparatus 900 has a turbine 904 rotated by a combustion gas, a combustor 906 for combusting a gaseous mixture of fuel and air, a fuel control valve 908 for adjusting the amount of fuel to be supplied to the combustor 906, an air compressor 910 for transferring air to the combustor 906 under pressure, and a controller 912 for indirectly controlling the turbine 904. The combustion apparatus of the aforementioned embodiments is used as the combustor 906 in FIG. 38.

The turbine 904 has a plurality of rotary vanes, which are not shown in the drawings, rotated by receiving a combustion gas 926, is connected to the air compressor 910 via a rotational shaft 914, and is rotatably supported in a casing, which is not shown in the drawings. The air compressor 910 is driven via the rotational shaft 914 by the turbine 904 and is configured so as to compress air 916 supplied into the air compressor 910. The air compressor 910 is connected to the combustor 906 via a pipe 918. The air 920 compressed by the air compressor 910 is supplied via the pipe 918 to the combustor 906.

The fuel control valve 908 is disposed upstream of the combustor 906. Fuel 922 supplied from a fuel supply source, which is not shown in the drawings, passes through the fuel control valve 908, and is then supplied to the combustor 906. The fuel control valve 908 is operable to vary an opening of the valve. The opening is controlled

via a control signal line 924 by the controller 912 to adjust the amount of fuel 922 to be supplied to the combustor 906.

The fuel 922 and the compressed air 920 supplied to the combustor 906 form a gaseous mixture in the combustor 906. When the gaseous mixture is combusted in the combustor 906, a combustion gas 926 having a high temperature and a high pressure is generated. The generated combustion gas 926 having a high temperature and a high pressure is supplied to the turbine 904 to rotate the turbine 904 at a high speed. The turbine 904 is coupled directly to the power generator 902 via the rotational shaft 914. When the turbine 904 is rotated, the power generator 902 is rotated to generate power.

A rotational speed detector 928 for detecting a rotational speed of the turbine 904 is provided near the rotational shaft 914 (near the power generator 902 in FIG. 38). Information of the rotational speed detected by the rotational speed detector 928 is transmitted through a signal line 930 to the controller 912. An arrangement and effects of the combustor 906 are the same as those of the combustion apparatus in the aforementioned embodiments.

As described above, when the embodiments of the present invention are applied to a general combustion apparatus, it is possible to positively control and generate burnt gas recirculation with a simple structure. Thus, the stability can be enhanced, and effects of burnt gas recirculation can be maximized.

Further, since effects of burnt gas recirculation can be maximized with high stability, it is possible to perform combustion with a combustion gas having a high temperature and a low oxygen concentration to achieve pre-evaporation combustion having stable evaporation characteristics in a case of liquid fuel, premixed combustion independent of gaseous fuel or liquid fuel, slow combustion, uniform combustion with a low maximum flame temperature, and combustion with a low average flame temperature due to the heat capacity of an inert gas in the combustion gas. Thus, it is possible to provide a combustion apparatus which can suppress generation of thermal NOx, which has been difficult to suppress with the conventional technology.

Since an inner wall of the combustion apparatus is suitably cooled by an air flow having a low temperature, it is possible to provide a combustion apparatus having a high durability.

Alternatively, it is possible to provide a combustion apparatus which can readily use a heat resistant material such as ceramics. Further, since disassembly and replacement are facilitated, it is possible to provide a combustion apparatus having easiness of maintenance.

When auxiliary fuel nozzles are provided, it is possible to provide a combustion apparatus which can suppress generation of thermal NOx in multi fuel combustion of gaseous fuel/liquid fuel and combustion with fuel or a waste liquid having a low heating value.

When the aforementioned embodiments are applied to a primary combustion zone of a gas turbine combustion apparatus, it is possible to positively control and generate burnt gas recirculation with a simple structure. Thus, the stability can be enhanced in a primary combustion zone, and effects of burnt gas recirculation can be maximized.

Further, since effects of burnt gas recirculation can be maximized with high stability, it is possible to perform combustion with a combustion gas having a high temperature and a low oxygen concentration to achieve pre-evaporation combustion having stable evaporation characteristics in a case of liquid fuel, in which it has been difficult to reduce NOx with the conventional technology, premixed combustion independent of gaseous fuel or liquid fuel, slow combustion, uniform combustion with a low maximum flame temperature, and combustion with a low average flame temperature due to the heat capacity of an inert gas in the combustion gas. Further, since a primary combustion zone can be designed so as to be leaner, it is possible to provide a gas turbine combustion apparatus which can suppress generation of thermal NOx by lowering a combustion temperature.

Furthermore, since an inner wall of the combustion apparatus is suitably cooled

by an air flow having a low temperature, it is possible to provide a gas turbine combustion apparatus having a high durability.

Further, it is possible to provide a gas turbine combustion apparatus which can readily use a heat resistant material such as ceramics. Furthermore, since disassembly and replacement are facilitated, it is possible to provide a gas turbine combustion apparatus having easiness of maintenance.

When auxiliary fuel nozzles are provided, it is possible to provide a gas turbine combustion apparatus which can suppress generation of thermal NOx in multi fuel combustion of gaseous fuel/liquid fuel and combustion with fuel or a waste liquid having a low heating value.

The embodiments described above can be modified within the scope of the present invention. A technical extension of the present invention should be determined based on the description of claims. That is, the illustrated embodiments are described by way of example, and do not limit the scope of the present invention.

For example, in the first embodiment to the fourth embodiment, each of the containers 12, 112, 212, and 312 has an annular (ring) cross-sectional shape. However, the cross-sectional shape of the container may be changed into a desired shape. Further, the container may have an annular shape including two polygons in which one completely encloses the other as long as a swirling flow is formed in the container. Alternatively, the cross-sectional shape of the container 12, 112, 212, or 312 may be varied in an axial direction at a location (axial location) other than locations at which the air inflow portions 20 are formed.

Further, air inflow ports may arbitrarily be provided on the annular container 12, 112, 212, or 312 or the inner side portion of the secondary annular container 402, mainly for cooling wall surfaces of the annular container 12, 112, 212, or 312 or the secondary annular container 402. When the inner side of the annular container 12, 112, 212, or 312, or the inner cylinder 404 of the secondary annular container 402 is made of a heat resistant material, such air inflow holes may not be provided. Further, combustion air

required for combustion may be supplied through these air holes at the downstream side of the air inflow portions 20. The aforementioned equivalent structures of the container can be applied to all of the aforementioned embodiments.

Further, the shape of the inflow casing 14 may arbitrarily be deflected in the first embodiment to the fourth embodiment. For example, the inflow casing of the embodiments, which has a structure in which air flows from the close end 10, 110, or 210 in the axial direction, may be replaced with a structure having a scroll shape through which air flows in a circumferential direction and a shape to allow air to flow from a periphery of the outlet of the annular container 12, 112, 212, or 312 or the secondary annular container 402 in an opposite direction, which is not shown in the drawings. Further, as shown in FIG. 16, a back flow type inflow casing 14a, which is suitable for a centrifugal compressor and a turbine, may be used.

The embodiments described above can be varied within the scope of the present invention. A technical extension of the present invention should be determined based on the description of claims. That is, the illustrated embodiments are described by way of example, and do not limit the scope of the present invention.

Industrial Applicability

The present invention is suitably used for a combustion apparatus for supplying combustion air and fuel to a combustion chamber to mix and combust the combustion air and the fuel.